

## LANSCÉ DIVISION RESEARCH REVIEW

### Neutron Capture Measurements on Unstable Nuclei at LANSCE

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#### Introduction

The process by which a radioactive nucleus absorbs a neutron and emits gamma rays plays an important role in understanding archived nuclear tests and the production of elements in stars. We discuss why this process is important and describe results from a preliminary experiment, which may indicate that this reaction is difficult to calculate accurately.

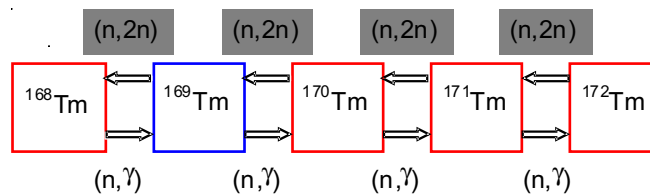
Nuclear physicists have studied the process known as neutron capture for 50 years and from this research have learned a great deal about the structure of the atomic nucleus. The capture process consists of a neutron striking and sticking to a target nucleus (becoming captured), followed by the new nucleus emitting characteristic gamma rays. To date, nearly all experiments have studied stable nuclei, and there is very little experimental information on neutron capture by radioactive nuclei. Applications that require capture reaction probabilities (known as cross sections) for radioactive nuclei must rely on calculated values.

A program is under way at the Los Alamos Neutron Science Center (LANSCÉ) to measure the capture cross sections on very small quantities of radioactive nuclei, about a milligram of material. These measurements are driven by the needs of several applied physics programs. The chief application is to understand nuclear device performance as part of the Stockpile Stewardship Program. Although no nuclear device tests are being conducted by the United States now, there is an extensive database from 50 years of nuclear testing. This data is being reviewed systematically using modern analysis and computational techniques, with a goal of understanding the physics of nuclear weapons.

One of the principal methods of diagnosing the performance of nuclear devices tested underground has been through the use of tracer isotopes. These were stable, mono-isotopic elements, such as thulium, inserted into the test device. The extremely high neu-

tron density during an explosion resulted in multiple nuclear reactions, involving both neutron capture and neutron "knockout reactions," where one or more neutrons are removed from the nucleus. These reactions produced radioactive isotopes, which were observed by drilling into the test region, removing samples, and analyzing them in the laboratory. The process of producing these isotopes is illustrated in Fig. 1, which shows that the radioactive isotope  $^{170}\text{Tm}$  can be made by an  $(n,g)$  reaction on the stable isotope  $^{169}\text{Tm}$ , and by an  $(n,2n)$  reaction on the radioactive isotope  $^{171}\text{Tm}$ . In order to understand the observed isotope distributions, accurate cross sections for all the reactions are needed, including reactions on radioactive isotopes.

Capture reactions are also of great interest to the study of the synthesis of elements that takes place in stars. About half of the nuclei heavier than iron are believed to have been produced by a "slow process" (s-process) of sequential neutron capture along the line of stable isotopes. This is thought to take place in low- to medium-mass stars at a certain stage of

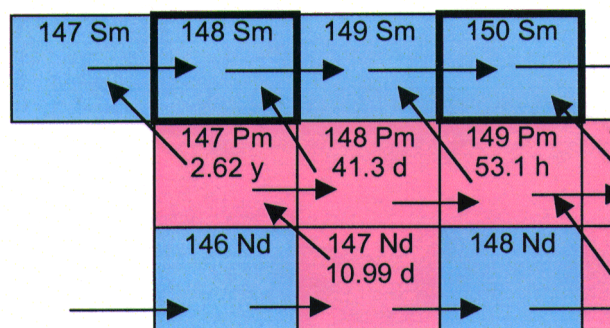


▲ **Fig. 1.** Multiple nuclear reactions based on the stable isotope  $^{169}\text{Tm}$ . Neutron capture reactions are indicated by  $(n,g)$ , and neutron knockout reactions by  $(n,2n)$ . The isotope  $^{169}\text{Tm}$  is stable, while the others are unstable

their evolution, or in red giant stars. The basic mechanism of the s-process appears to be understood. This is illustrated in Fig. 2, which shows the path of sequential capture in the region of the element samarium.

The branching of the capture path that occurs at radioactive isotopes is of particular interest. Here there is a competition between radioactive decay and neutron capture. The rate of capture depends on the capture cross section and the stellar neutron density. An important example is in the mass 147 to 149 region where several branchings occur. If the

capture cross sections are known, the neutron density at the place in a star where nucleosynthesis occurred can be inferred from the abundance of  $^{148}\text{Sm}$  and  $^{150}\text{Sm}$  observed in nature. Thus, an accurate knowledge of the neutron capture cross section on certain radioactive isotopes can lead to an estimate of an important stellar parameter, the neutron density, and a deeper understanding of how stars work.



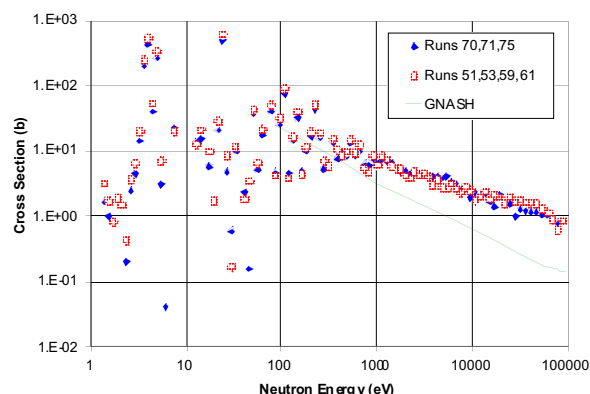
▲ **Fig. 2.** S-process path near masses 147 to 150. Red indicates unstable nuclei, and blue indicates stable nuclei observed in nature. Heavy outlines indicate nuclei that are produced only by the s-process.

Measurements on unstable nuclei are complicated by the need to handle radioactive targets safely. The Los Alamos National Laboratory offers several experimental facilities that combine to give it a capability that is unique in the world to make these measurements. First, there is the intense neutron source of the Manuel Lujan Jr. Neutron Scattering Center. This allows us to measure samples weighing about one milligram; other experimental facilities require 100 to 1,000 times as much material, sometimes even more. Next, there is the ability to produce and handle radioactive targets by the Nuclear and Radiochemistry Group of the Chemical Science and Technology Division. In addition to radiochemistry expertise, this group has recently built the Radioactive Species Isotope Separator, a magnetic isotope separator specifically designed to separate highly radioactive isotopes. Finally, an advanced, high-efficiency detector array, specifically designed to detect gamma rays from radioactive targets, has been proposed for LANSCE.

We have made preliminary measurements of neutron capture on the unstable nucleus  $^{171}\text{Tm}$ , which has a half-life of 1.9 yr, using an existing gamma-ray detector. This isotope was chosen because it is an isotope of Tm with applications to understanding archived data, it is easy to produce and purify, and it presented the lowest radiation hazard of all the possible targets. The stable isotope  $^{169}\text{Tm}$  was also

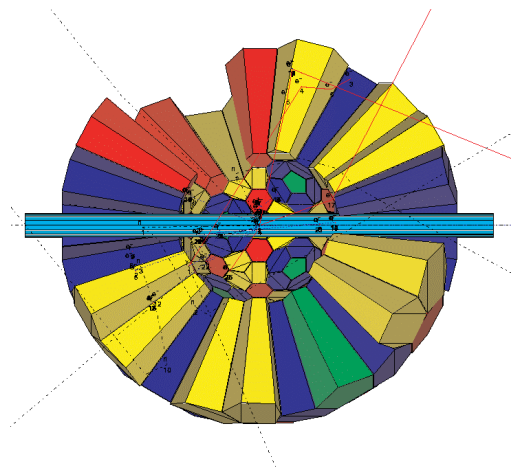
measured.

The measured cross section data for  $^{171}\text{Tm}$  is shown in Fig. 3. Also shown is a theoretical calculation using the computer program GNASH. The rapid swings in the data below 100 electron volts (eV) are due to nuclear "resonances." The region of interest is from about 1,000 to 100,000 eV of energy. In this region, the theoretical calculation under-predicts the data by a factor of 2 to 5. On the other hand, the theoretical calculation agreed very well with the data for the stable  $^{169}\text{Tm}$ . In general, the calculations reproduce very well the data on stable isotopes. The current measurement may indicate that certain parameters in the calculation cannot be simply extrapolated from a stable nucleus to its unstable neighbors.



▲ **Fig. 3.** Preliminary measurement of the neutron capture cross section of  $^{171}\text{Tm}$  compared to a theoretical calculation using the program GNASH. Data are shown for two different sets of runs, taken at different times during the experiment.

The results of the preliminary experiment were encouraging, and an advanced detector has been proposed. This "Detector for Advanced Neutron Capture Experiments" (DANCE) will consist of 160 barium fluoride crystals, arranged together like the panels of a soccer ball (see Fig. 4.). If funding for DANCE is procured, a program to measure several targets each year could be started in 2001. However, a smaller program using existing detectors could be started in 2000.



**Fig. 4.** Cutaway schematic of the 160-element DANCE detector. The crystals must have four different shapes to pack together in a ball, and each shape is indicated by a different color. The neutron beam is confined to the light-blue beam tube.

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